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|||| 1.25 |||| 1.4 |||| 1.6

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| 3.2 | 2.2

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| 4.0 | 2.0

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|||| 1.6

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TECHNICAL REPORT
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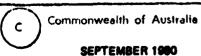## A COMPUTER BASED IONOSPHERIC SOUNDING AND HF NOISE
MEASURING SYSTEM

G.F. EARL

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A COMPUTER BASED IONOSPHERIC SOUNDING AND HF NOISE MEASURING SYSTEM

G.F. Earl

Sep 80

S U M M A R Y

A system for the automated collection of ionospheric backscatter sounding and HF noise measurement data is described. The system was configured around a PDP 11/40 minicomputer and modified Barry Research FMCW sounding equipment. The real time digital signal processing associated with the backscatter sounder and noise measurement systems is discussed. The data are displayed and recorded in a calibrated mode, and examples are presented. Deficiencies noted in the operation of the system, and plans for the introduction of oblique and vertical incidence sounding conclude the report.

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A system for the automated collection of ionospheric backscatter sounding and HF noise measurement data is described. The system was configured around a PDP 11/40 minicomputer and modified Barry Research FMCW sounding equipment. The real time digital signal processing associated with the backscatter sounder and noise measurement systems is discussed. The data are displayed and recorded in a calibrated mode, and examples are presented. Deficiencies noted in the operation of the system, and plans for the introduction of oblique and vertical incidence sounding conclude the report.

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LIST OF FIGURES

1. INTRODUCTION

The ionospheric sounding and atmospheric noise measuring system described in
this report was used to collect data in support of an Australian over-the-horizon
radar program.   The objectives of the experimental program were:

  (i) to collect backscatter sounding data for a synoptic study of propagation
       conditions,

 (ii) to collect noise data for a synoptic study of the HF noise background,

(iii) to collect data on RFI, in particular the large signal environment.

Each of the above objectives was characterised by continuous (24 hour/day)
data collection of calibrated estimates on magnetic tape for off-line analysis
at DRCS.   Backscatter sounder data could be collected between nominated lower
and upper frequencies.   In practice, data were routinely gathered between 6 and
29 MHz.   Likewise, while the atmospheric noise data could be collected between
nominated frequencies, in practice limits of 6 and 30 MHz were generally
employed.   The data on large signal RFI environment were required to define
receiver design requirements.

2. EQUIPMENT DESCRIPTION

2.1 Transmitter Site

Figure 1 is a block diagram of the transmitter site control computer, and of
the equipment associated with backscatter sounding.

The roles of the items of equipment shown in Figure 1 were as follows:

Log-periodic Antenna	– A single TCI model 547 log-periodic antenna used for backscatter sounder transmissions.
Power Amplifier	– A Servo-tuned Collins 208U-10 power amplifier provided a nominal 5 kW output.
FMCW Waveform Generator	– A Barry Research model 1022 FMCW waveform generator, modified in order that sweep limits were controllable, generated an FMCW signal sweeping at a 2 MHz/min rate.
Reference Frequency Source	– Hewlett Packard 105B reference oscillator used to provide site with reference frequencies of 5 and 10 MHz. All synthesisers, FMCW waveform generators etc. were driven from this unit.
Equipment Status	– Enabled monitoring of equipment status eg.

    (i) what equipment was in manual or computer control,

    (ii) various status signals associated with the power amplifier - tuning complete, VSWR, etc.

Input/Output Interface	- Enabled the computer to control all equipment, so that no manual intervention was necessary during routine operations. All of the equipment could be switched to manual control if necessary, eg. for maintenance.
PDP11/10 CPU	- Fitted with 16K of core memory. Responsible for equipment control and monitoring. Transmitter site program was coded entirely in assembly language.
Terminal	- An 'LA36 Decwriter' combination keyboard and printer.
Serial data I/O interface and VHF Link	- Handled messages to and from receiver site

This site operated as a slave to the receiver site, with messages being passed over the VHF data link.   Upon receipt of a message, any necessary changes to the equipment were implemented under computer control via the input/output interface.   For instance, prior to a backscatter sounder run the computer would be required to:

  (i)   load the upper and lower frequency limits into the FMCW waveform generator,

 (ii) retune the power amplifier to the lower limit,

(iii) enable a gate causing the FMCW waveform to be reset in synchronisation with the corresponding waveform at the receiver site.

A third mode of operation ie. aside from normal computer control, or the manual alternative, allowed the equipment to be controlled by the computer, but with data entered via the keyboard as opposed to the VHF data link.

2.2 Receiver Site

Figure 2 depicts the equipment configuration at the receiver site.   The roles of the items of equipment shown in Figure 2 were as follows:

Calibrated noise source	- provided broadband HF noise at a known spectral density.
Sounder calibration unit	- provided an FMCW signal of known power level.
Receiver input unit	- enabled a variety of antennas, noise source and 50 ohm termination to be selected as receiver input.
Receiver	- used to receive signals for both backscatter sounding and noise measurements. It was a modified Barry Research receiver.
FMCW waveform generator	- provided a VHF local oscillator signal for 'deramping' backscatter sounder signals. (Deramping is the term used to describe the process whereby received FMCW signals are mixed with a local oscillator FMCW signal in order to produce beat frequencies, the beat frequency being proportional to the group delay of the received signal).

Fluke synthesiser	– provided a programmable source of CW signals to be used as the VHF variable frequency oscillator in the noise measuring mode.
Spectrum analyser	– enabled real time monitoring of sounder baseband signals independently of computer processing.
A/D converter	– 12-bit device with multiplexer. Sampling rate determined by timing card under computer control.
Input/Output interface	– played same role as equivalent at transmitter site ie. computer control of equipment including equipment status monitoring.
Reference frequency source	– Hewlett Packard 105B reference oscillator used in the same role as that described for the transmitter site.
Systron-Donner time unit	– used to provide time of day information both visually and to computer systems.
Equipment status	– identical function to unit at transmitter site discussed previously.
PDP 11/40 computer	– featured floating point processor and 80K of memory. Software operated under the Digital Equipment Corporation operating system, RSX-11D. Responsible for equipment control, signal processing and control of peripherals.
Programmable signal processor	– developed within Electronics Research Laboratory. Used to implement spectral analysis in real time.
Tektronix model 4012 display/ keyboard	– used by operators for equipment control purposes and a variety of displays.
Disk	– RK05 disk with a capacity of 1.2 million 16-bit words. Used to store operating system, user tasks and data files.
Magnetic tape	– data storage at 800 bpi. Typically, two 2400 ft tapes were required each day.
Serial data I/O interface and VHF Link	– used to command transmitter site as previously discussed.

The system alternated between two data gathering modes viz 'sounder' for backscatter sounder data, and 'surveillance' for HF noise data. Using the standard frequency limits discussed previously, the system would remain in each mode for approximately 15 minutes.

2.2.1 Sounder Mode

In this mode the receiver input unit selected the antenna used to collect backscatter sounder data as the signal source. This antenna was a broadside array, 160 m in length, of 'dual whip' elements having a single beam in the required direction. The received signal was deramped within the receiver using the FMCW waveform generator to provide the variable

frequency oscillator signal to the first mixer.   Following two further
stages of frequency translation and amplification, the received signal
was translated to baseband and passed to the A/D converter.   A calibration
signal was injected within the receiver input unit.   This signal was
synthesised in such a manner as to cause it to appear at the receiver
output at a fixed frequency.   The strength of other signals appearing at
the receiver output could be inferred by reference to the calibration
signal.   The processing of the sounder signals is discussed in Section 3.1.

2.2.2 Surveillance Mode

As was the case in the sounder mode, the receiver input unit was used to
select the desired signal source.   A variety of antennas, differing in
directivity were available for selection.   In surveillance mode the FMCW
local oscillator signal was replaced by a CW signal generated by a 'Fluke'
6100B synthesiser.   When in surveillance mode the same sections of the
receiver were used up to and including the second mixer.   The increased
bandwidth of the surveillance mode (viz 20 kHz compared with 2kHz in
sounder mode) then demanded a separate receiver channel, including
further amplification and translation to baseband.   A multiplexer was used
to access the same A/D converter as was used in sounder mode.   Calibration
of the surveillance data was achieved by substituting the calibrated noise
source in place of the antenna on which data had been collected.

A photograph of the receiving system is included as Figure 3.   The
modified Barry Research sounder system is housed in the right hand rack.
The facsimile recorder was included to support a manual 'back-up' mode of
operation, but apart from its use in the commissioning of the present
system, it was not used.   The left hand rack contains equipment developed
within DRCS to support the sounder and surveillance systems, together with
commercial equipment including the Fluke synthesiser, general purpose HF
communications receiver, and monitor oscilloscope.

3.   ON-LINE PROCESSING

3.1 Sounder Processing

The FMCW sweep rate afforded by the Barry Research sounding equipment was
33.33 kHz s^{-1}.   The required range coverage was 0 to 9000 km at a nominal
slant range resolution of 50 km.   The range coverage of 9000 km corresponds
to a time delay of 60 ms, which at the sweep rate of 33.33 kHz s^{-1} determines
that the deramped signals will occupy a bandwidth of 2.0 kHz.   A coherent
integration time of 0.1 s was chosen since it provided an   r.f. bandwidth of
close to 3 kHz, consistent with the slant range objective.   Details of the
sounder processing are included in Figure 4.   The backscatter sounder data
of interest is contained within the frequency limits 2.0 to 4.0 kHz,
corresponding to the range coverage of 0 to 9000 km.   The frequency ranges
dc to 2.0kHz and 4.0 to 5.0 kHz are used as guard bands to prevent spectral
aliasing ie. the 'folding' of unwanted signals into the band of frequencies
occupied by the backscatter sounder signals.   While the size of the guard
bands may appear excessive (only 40% of the processed data contains useful
information), in practice no significant penalty is paid since the time
required to process the data was considerably less than the 0.1 s spent
acquiring it.   The advantage of such a scheme is the ability to relax the
specifications of anti-aliasing filters within the receiver.

The calibration signal is located at 1953.125 Hz (the precise location of an

FFT estimate). As discussed previously, absolute power levels of backscatter
signals were inferred by comparison with the calibration signal.

Thus, the spectral processing yielded absolute estimates of ground backscatter
signal strength at 44 km separation. These raw estimates pertained to 3.3 kHz
of the HF spectrum. In order to decrease the variance of the results, and
at the same time reduce the volume of data, the data in 200 kHz bands of the
HF spectrum were then averaged to yield backscatter signal strengths corres-
ponding still to 44 km spatial separation, but averaged over 200 kHz. This
is equivalent to assuming that structural changes in ionospheric ground
backscatter are insignificant when considered in terms of HF frequency changes
of 200 kHz, and recorded data has validated this assumption.

When using the standard frequency limits of 6 to 29 MHz, a matrix of 115
(frequency) by 200 (range) points was used to define an ionogram, and this
volume of data was recorded on magentic tape. A data file of the most
recent ionogram was also maintained on the disk. This data could be
displayed on the Tektronix terminal on demand, to a maximum group range of
3000 km. Hard copies could be made using the electrostatic printer attached
to the main radar. An example is shown as Figure 5. Absolute signal
strengths can be inferred by reference to the information supplied at the top
of the ionogram. Note the presence of RFI due to the 15 and 17 MHz broadcast
bands.

3.2 Surveillance Processing

Before proceeding to details of the analysis of this data, Figure 6 is
included to provide details of the surveillance processing on a single 20kHz
band of frequencies. The coherent integration time of 5 ms yielded raw
spectral estimates at a frequency separation of 200 Hz. In order to stabilise
these estimates (ie. reduce their variance), 10 raw estimates were used in
order to form averages at 2 kHz separation.

The surveillance processing may be understood with reference to Figure 7.
Suppose the receiver was tuned (using the Fluke synthesiser) to acquire data
in the 20 kHz band indicated. Then the data entering the A/D converter was
a result of the amplification and frequency translation of the 20 kHz band of
the HF spectrum to which the receiver was tuned eg. 17.460 to 17.480 MHz.
This data was stored in the right hand section of dual port memory.
Concurrent with the collection of this data, the Programmable Signal Processor
was used to process data located in the left hand section of dual port
memory, which had previously been collected when the receiver had been tuned
20 kHz lower in frequency ie. 17.440 to 17.460 MHz in the present example.

When the processing was complete the results were written into memory, the
processor began processing the newly acquired data, the receiver was retuned
20 kHz higher in frequency, and new data was acquired via the A/D converter.
This "inner loop" of processing was carried out across 1 MHz of bandwidth
ie. 17.0 to 18.0 MHz in the example quoted.

The end result of the processing described above resulted in 10 spectral
estimates (at 2 kHz resolution) being written into memory. The "inner
loop" of 1 MHz could be scanned a specified number of times. The normal
number of scans employed was 10, requiring approximately 10 s, and on each
pass a running sum of the spectral estimates was computed in order that a
final average value could be determined. In addition, maximum and minimum
values were updated on each pass in order to gain some appreciation of
fluctuations about the average. When an "inner loop" of 1 MHz had been

scanned the prescribed number of times, data pertaining to that 1 MHz band were transferred from memory onto disk. Exactly the same processing as described for the 1 MHz band cited above was then repeated on the next 1 MHz band in an "outer loop", the limits of which could be controlled, and which were normally set to 6.0 and 30.0 MHz.

Thus, at the completion of the data gathering phase of a surveillance run, the HF spectrum was specified at 2 kHz resolution by an array of floating point numbers, which following calibration would yield absolute values of spectral density. For the standard limits of 6 and 30 MHz, 12000 numbers were stored on disk.

The receiver input unit then selected the calibrated noise source, and data was acquired at a fixed frequency and processed in the same manner as described for data acquired using an antenna. The data collected using the noise source was then used to convert the spectral estimates derived using an antenna into absolute units (dBw/2 kHz). The calibrated data (typically 12000 estimates) replaced the uncalibrated data as disk files and were also recorded on tape for off-line analysis.

At this stage of the processing no attempt had been made to distinguish clear channels (from which background noise estimates could be derived), from occupied channels (Radio Frequency Interference). A number of algorithms were evaluated, both on-line and off-line, for estimating background noise spectral density from data contaminated by RFI. The most successful algorithm, in the sense of providing estimates closest to those resulting from an observer 'eye-balling' the data, consisted of estimating the lower decile of the spectral estimates pertaining to 0.5 MHz bands of the HF spectrum. Under most conditions the lower decile was found to be a good estimate (± 2 dB) of the median noise except for the international broadcast bands where the estimate was consistently high. In fact the dynamic range of the measuring system, both analogue and digital aspects, was inadequate to allow background noise estimates to be made in the presence of the strong interference prevalent in these bands. Accordingly, the broadcast bands were deleted in the analysis of background noise levels. Figure 8 is an example of noise data measured on a 5.4 m omnidirectional whip antenna. The data as presented is relevant to the whip antenna, without the known corrections having been made for mismatch loss, cable attenuation etc. as would be required before a comparison with CCIR noise data could be undertaken.

4. SYSTEM FEATURES AND DEFICIENCIES

4.1 Features

Features of the system are set out in Figure 9.

Unmanned operation	- allowed synoptic data gathering program to run 24 hours/day.
Flexibility	- software changes allowed the equipment to be controlled in response to new data gathering programs.
	- Disk data files enabled on line processing and data display.
	- Magnetic tape data provided permanent retention of data and off-line processing including statistical analysis.

Displays and hard copies   - these were to facilitate the interpreta-
                                    tion of data in real time, but caused
                                    difficulty operationally, the nature
                                    being discussed in the next section.

On-line routine checkout   - when the calibrated noise source was
                                    selected and the receiver gain set to a
                                    constant value, the results of the spectral
                                    processing yielded a result which could
                                    be compared with a reference value in
                                    order to validate the receiving and pro-
                                    cessing system.   A tollerance of ± 2 dB
                                    was allowed for drift in receiver gain,
                                    and if this tolerance was exceeded the
                                    operators were informed via the visual
                                    display unit (VDU) and an external status
                                    display.   This feature allowed the real
                                    time identification of equipment faults
                                    or equipment which had inadvertently been
                                    left in manual control, and considerably
                                    reduced the posibility of inadvertently
                                    recording long periods of invalid data.

Parameter definition under   - if required, in order to suit the demands
keyboard control   of the experimental program, various ex-
                                    perimental parameters could be redefined
                                    via the keyboard.   For instance, the
                                    frequency limits of the backscatter sounder
                                    and noise measuring systems could be set
                                    as desired.   Antennas used in the noise
                                    measuring program could be either included
                                    or excluded.

5 dB receiver noise figure   - high sensitivity.

Ability to measure large signals - if necessary an attenuator at the front
                                    end could be used to attenuate large
                                    signals, albeit with a degraded noise
                                    figure.

4.2 Deficiencies

Deficiencies which became apparent in the operational use of the equipment
are listed in Figure 10.

Inadequate visual display   - the Tektronix 4012 display unit was the
capability   only display unit/keyboard attached to
                                    the system.   Consequently displays that
                                    should be available continuously, eg.
                                    backscatter ionograms, system configura-
                                    tions, were not available while another
                                    display was presented.   Since some
                                    displays took several minutes to present,
                                    this was at times particularly frustrating.
                                    At least two other VDUs could have been
                                    profitably used, each assigned a specific
                                    display/monitor role.

Difficulty in obtaining hard copies	- hard copies could only be obtained by transferring files to the radar computer and requesting copies be made on the electrostatic plotter attached to that computer. The hard copy procedure was time consuming on the radar computing system. The ideal solution would have been a hard copy unit directly attached to the VDU.
RFI in night time ionograms	- RFI in night time ionograms frequently rendered them useless. Algorithms to prevent this contamination were required on-line, but the effort to implement them during the experimental program was not available. Algorithms designed to contend with RFI were successfully implemented off-line in a statistical analysis of daytime data, and it is intended to incorporate this feature on-line in the system outlined in the following section.
Site synchronisation at night	- at night the problem of enhanced RFI and background noise aggravated the problem of detecting the weak ground wave signal from the transmitter site which was used in order to synchronise the FMCW waveforms of the sounder system. If for any reason synchronisation was lost at night, difficulty was experienced in re-establishing synchronisation. An independent 'keep alive timing system' at each site, providing synchronised timing pulses, would have been preferable.
Lack of transmitter power monitor	- the transmitter site lacked a monitor of the power actually being radiated by the backscatter sounder. Thus there was some uncertainty at any given time as to the discrepancy between actual and nominal radiated power levels. A directional coupler in the antenna feeder would have enabled actual power levels to have been deduced and recorded.

5. FUTURE PLANS

The system described in this paper was decommissioned in December 1978. A new system is currently under development. In addition to overcoming all of the deficiencies noted in the previous section, the new system will feature an oblique sounding system. Vertical incidence sounding between the transmitter and receiver sites will also be introduced.
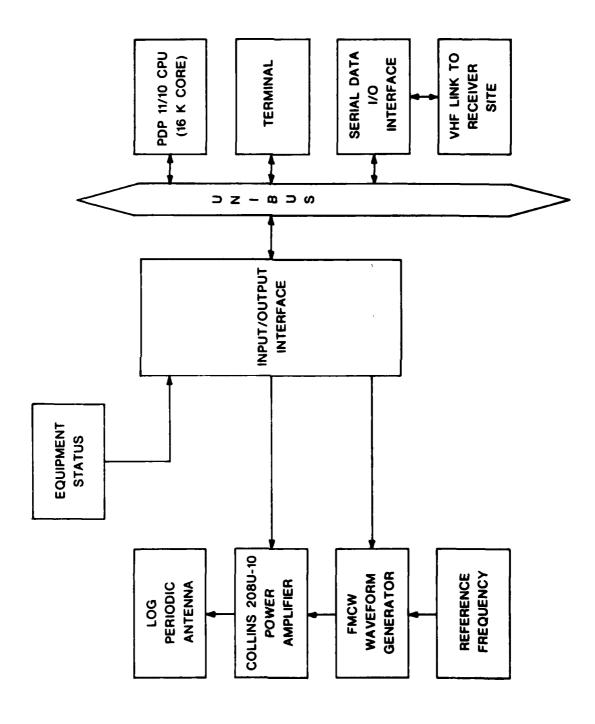
6. ACKNOWLEDGEMENTS

Figure 1. Transmitter site equipment configuration
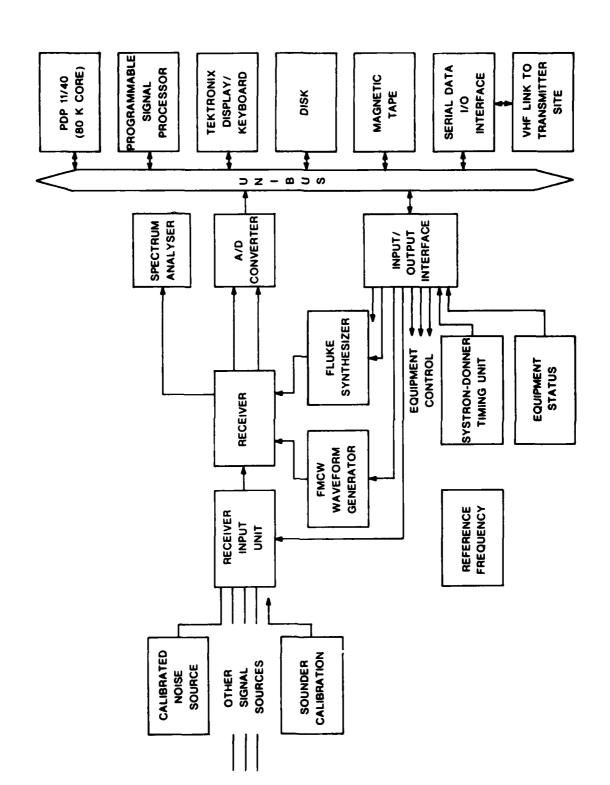
Figure 2. Receiver site equipment configuration
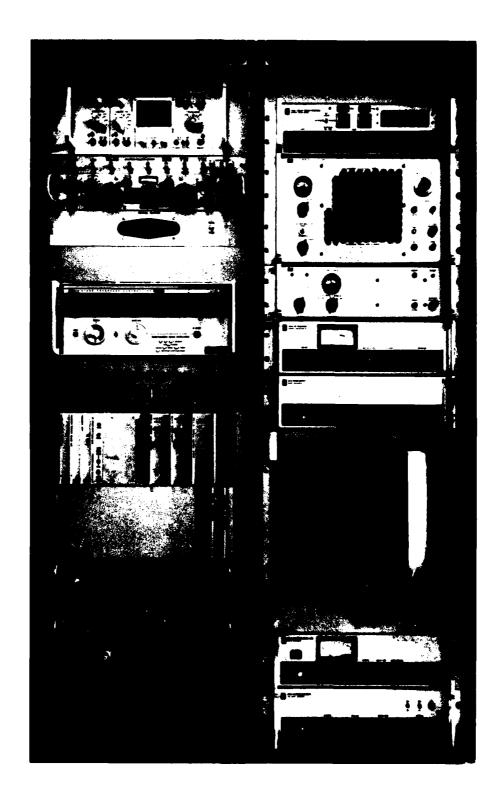
Figure 3.   Receiver site equipment

SOUNDER PROCESSING

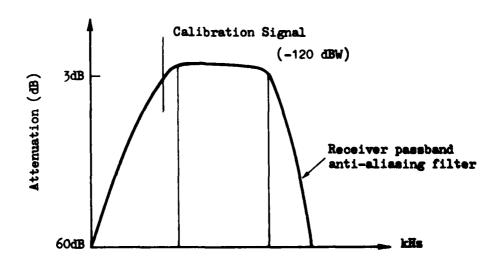|	
FMCW sweep rate	33.3 kHz/s
Coherent integration time	0.1 s
A/D rate	10 kHz
Number of points in FFT	1024
Fundamental frequency separation	9.77 Hz
Slant range separation	44 km
Total range coverage (magnetic tape output)	9000 km
Total range coverage (real time display)	3000 km

Figure 4. Sounder processing
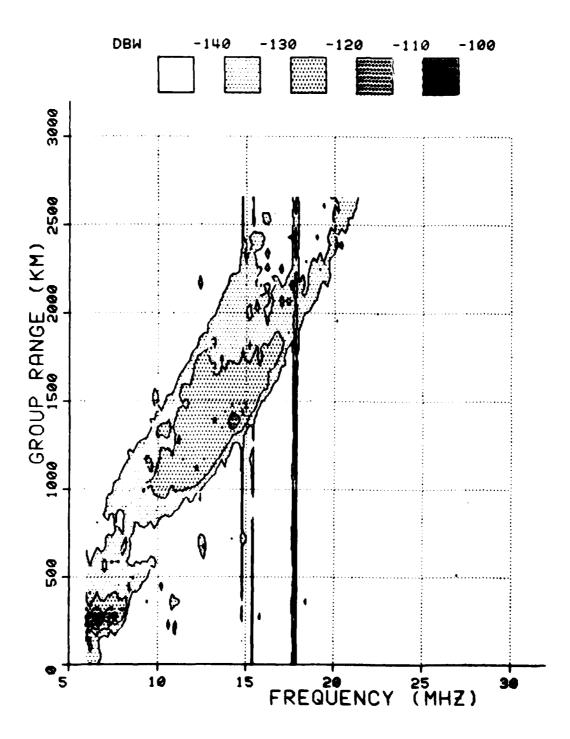
131:05:10:56 -- 05:22:20   11-MAY-77

QUARTER ARRAY

DBW   -140   -130   -120   -110   -100

Figure 5. Backscatter ionogram

SURVEILLANCE PROCESSING

A/D rate	51.2 kHz
Integration time	5.0 ms
Number of points in FFT	256
Fundamental frequency separation	200 Hz
Resolution used to define spectra	2 kHz

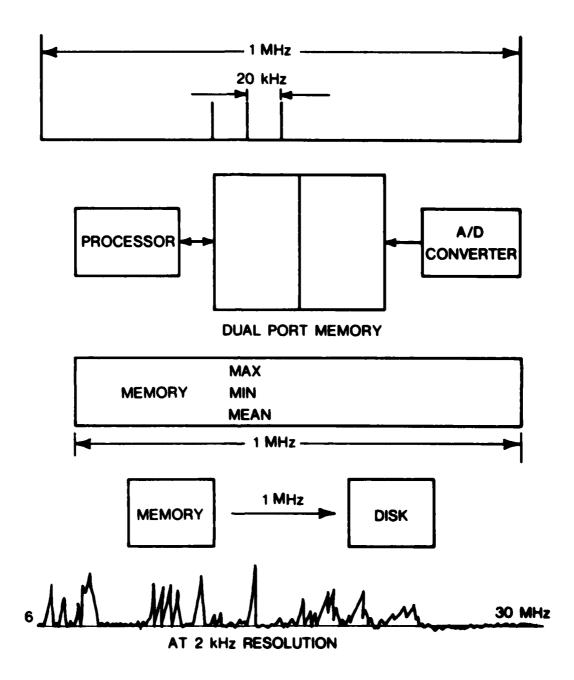Figure 6. Surveillance FFT details
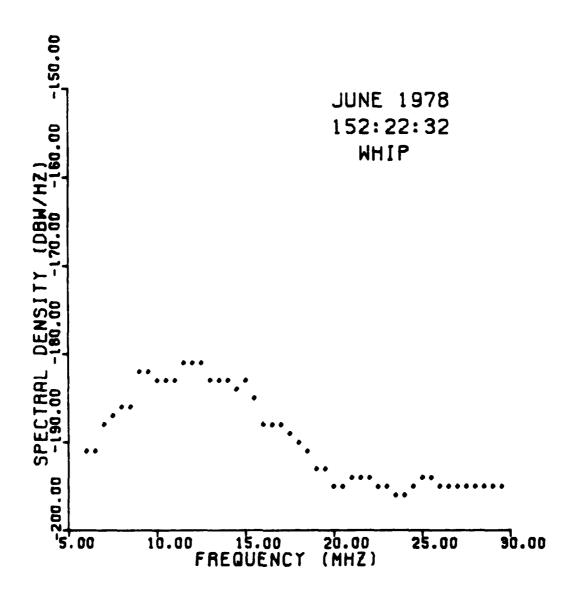
Figure 7. Surveillance processing

Figure 8. Atmospheric noise

SYSTEM FEATURES

Unmanned operation

Flexibility

- all equipment under computer control

- disk data

- magnetic tape data

Displays and hard copies

On-line routine checkout

Parameter definition under keyboard control

- frequency limits

- antenna selection

- etc.

5 dB noise figure

Ability to measure large signals

Figure 9. System features

SYSTEM DEFICIENCIES

- Lack of visual display units

- Difficulty of obtaining hard copies

- RFI in night time ionograms

- Site synchronisation at night

- Lack of transmitted power monitor

Figure 10. System deficiencies

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